A physical layer simulator for WiMAX

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Abstract – A physical layer simulator for the WiMAX technology is presented in this paper. The simulator encompasses the main blocks that build the physical layer from IEEE 802.16e. Using the simulator, BER curves for different scenarios are presented.

Keywords: WiMAX, simulation, physical layer

I. INTRODUCTION

The WiMAX (Worldwide Interoperability for Microwave Access) technology represents a powerful candidate for the fourth generation of mobile communication systems. Among different versions of the standard, the most successful commercial implementation was brought by IEEE 802.16e. sometimes referred to as mobile WiMAX. Some state-of-the-art signal processing and networking algorithms and techniques are proposed by the technical specifications of IEEE 802.16e for layers 1 and 2 (PHY and MAC respectively).

The MAC layer in WiMAX is oriented on the Quality of Service (QoS). Thus, several data delivery services (UGS, rtPS, nrtPS, ertPS, BE) are defined in the standard for the radio interface, to accomodate different types of applications. Furthermore, the air interface in WiMAX relies on an intelligent multiple access mechanism. In uplink (UL), time and frequency resources are granted by the Base Station (BS) upon demand, whereas in DL, the Mobile Stations (MS) are scheduled to receive data mainly based on the QoS parameters that must be fulfilled for every particular Service Flow. The QoS parameters are taken into account for resource allocation in UL too. Due to this intelligent scheduling, there is no contention on the air interface, excepting some parts of the physical frame involved in particular network procedures (network entry, handover) [1].

MAC layer resides on the services provided by the PHY layer. Its most important feature is the use of OFDMA (Orthogonal Frequency Division Multiple Access) technique. OFDMA is an extension of OFDM, that provides additional, multiple access capabilities. Other features of the physical layer are link adaptation and the use of several Adaptive Antenna Systems (AAS) techniques [2]. For the DL/UL separation, even if both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) are allowed, the system profiles given by WiMAX Forum for mobile WiMAX are based on TDD.

The basics of the PHY layer in WIMAX are presented in section II. The simulator is described in section III. Some simulation results are presented and commented in section IV. The last section is dedicated to conclusions an further work objectives.

II. PHY LAYER IN WIMAX

The PHY layer in WiMAX relies on OFDMA, which can be seen as an extension of OFDM. The later is a multi-carrier modulation technique that exhibits excellent robustness against the impairments introduced by the transmission channel. An OFDM symbol is a sum of multiple orthogonal carriers (the complex exponentials from relation 1), modulated by the data symbols to be transmitted through the channel ($X[k]$):

$$s(t) = \left(\sum_{k=0}^{N-1} X[k] \cdot e^{j \cdot k \cdot 2\pi \cdot \Delta f \cdot t}\right) \cdot p_T(t) \qquad (1)$$

$p_T(t)$ is a sliding window of duration T which localizes the signal on the time axis and determines the duration of an OFDM symbol ($T = 1/\Delta f$ in order to achieve subcarriers' orthogonality). If the digital symbols to be transmitted $X[k]$ came from different users, then OFDM transforms into OFDMA. This requires perfect synchronization of the system, but brings an additional dimension of multiple access too. Thus, apart from the time division multiple access (all the carriers that compose different OFDM symbols may be dedicated to different users, on a symbol-by-symbol basis), a frequency division multiple access may be achieved. This means that, for the duration of a single OFDM symbol, the carriers may be shared by different users, according to the scheduling made by the MAC layer. Most of the OFDM/OFDMA practical implementations are based on the computation of the Inverse Fast Fourier Transform (IFFT) in the modulator and of the direct transform in the demodulator. This allows simple, signal-processing based implementation of the multi-carrier modulation, eliminating the need for expensive oscillators required to generate the orthogonal carriers.

A generic structure of the PHY layer frame in TDD WiMAX is shown in fig. 1 [2]. The resources are allocated on a two-dimensional, time-frequency grid: subchannels (collections of subcarriers) are defined on the y axis, while OFDM symbols are allocated on the x axis. Thus, subchannels represent logical resources that may be shared among different users (fig. 2). Apart from the zones that convey data (bursts), some control information regions (DLMAP, ULMAP, FCH etc) are defined within the frame. Furthermore, some of the carriers do not transport any kind of system information, being used for special purposes (pilot subcarriers- channel estimation, guard subcarriers- at the edge of the band).

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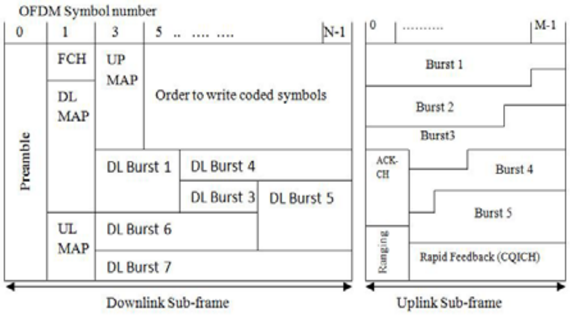

Fig. 1: WiMAX radio frame (TDD).

The subcarriers that compose the subchannels may or may not be adjacent in the physical spectrum. This depends on the strategy employed to map the physical resources (subcarriers) onto logical resources (subchannels), process that is referred to as permutation [3]. Several permutation types are defined by the standard, suited to different purposes. FUSC (Fully Used Subchannelization) makes full usage of the achievable frequency diversity: any available subcarrier within the whole spectrum may be allocated to any subchannel. PUSC (Partially Used Subchannelization) firstly splits the available subcarriers in several groups (segments). The subcarriers are then mapped to subchannels within every segement, independently. This approach is still oriented to frequency diversity, and allows a kind of "virtual sectorization": different regions of the cell will correspond to different segments. By coordinated planning, the neighbor cells may use the same frequency band, the segmentation allowing to reduce the interference. AMC (Adaptive Modulation and Coding) is the name given to an adjacent permutation: the subcarriers that compose the subchannels are adjacent in the spectrum. This approach reduces the complexity and is well suited for the channels that change slowly in time. Channel estimation is easier (due to the fact that the carriers are adjacent), and consequently the link adaptation becomes simpler too, which explains the name given to this permutation.

The minimum amount of resources that may be allocated for a user is called slot. The way that the slot is composed varies for different types of permutations. However, as a rule of thumb, we may state that a slot is composed of one or several subchannels (on the *y* axis, fig. 1) and one ore several OFDM symbols (on the *x* axis, fig. 1). Furthermore, each of the permutation modes in WiMAX has its definition for a subchannel. There is also a difference between allocation of the data and pilot subcarriers in the subchannels with respect to the different possible permutation modes. Thus, for DL FUSC and PUSC, the pilot tones are allocated first. The remaining data subcarriers are divided into subchannels that are used exclusively for data. For UL PUSC, the set of used subcarriers is first partitioned into subchannels and then the pilot subcarriers are allocated from within each subchannel.

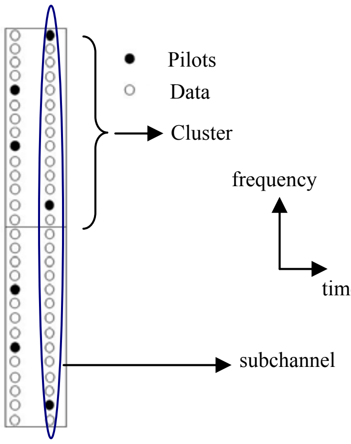

Fig 2. Logical resources for DL-PUSC.

Thus, in the FUSC mode, there is one set of common pilot subcarriers, while in the uplink PUSC mode, each subchannel contains its own set of pilot subcarriers. For the downlink PUSC mode, there is one set of common pilot subcarriers for each segment.

An example of physical layer logical units defined in WiMAX for DL-PUSC is shown in fig. 2.

An important step of the PHY layer processing is the error protection coding. This is linked to the concept of AMC too. Thus, users with good radio conditions may be scheduled to transmit with a high-level modulation (e.g. 64 QAM) and with a high rate of coding. As channel coding techniques, several options are proposed by the standard: convolutional coding, turbo-coding and LDPC coding. However, most of the manufacturers prefer convolutional turbo-codes (CTC) that achieve a good trade-off between complexity and performance. The digital modulation schemes that are proposed for WiMAX are QPSK, 16QAM and 64QAM. In combination with different coding rates, these modulations compose the modulation and coding profiles, used in the AMC process (e.g. QPSK ½, 16 QAM ½ etc.).

III. PHY LAYER SIMULATOR

The PHY layer simulator block scheme is shown in fig. 3. Its structure is based on [4]. Its blocks implement the PHY layer processing operations described in the previous section. The simulator eases the understanding of the PHY layer signal processing steps. Furthermore, it allows to assess the BER performance of the system in different scenarios.

The simulator is implemented under Matlab 7.1. The Matlab functions that implement functional blocks from fig. 3 are briefly described in the following.

Source: generates data blocks (bits of "1" and "0" respectively) to be jointly encoded by the encoder. Since the later is based on CTC, which uses an incorporated interleaver, the output of the block must be adapted to the size of the subsequent interleaver. This is done via an input parameter of the block.

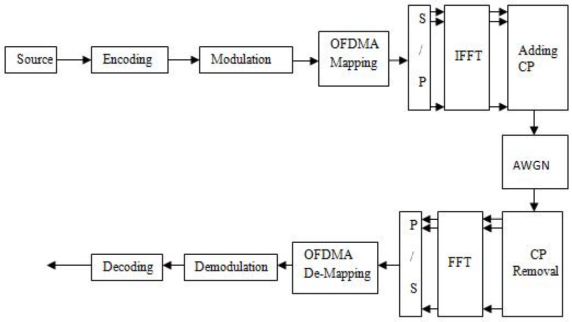

Fig 3. The block scheme of the WiMAX simulator

Encoding: It is known that parallel concatenation of *r*-input binary RSC codes offers several advantages in comparison with classical binary turbo codes (TCs). As advantages, we may mention: better convergence of the iterative process and robustness of the decoder. [5]. In this work we used duo-binary TC with rate equal to 1/2. It consists from two convolutional codes, in parallel concatenation, with memory 3 and rate 2/3 and encoder polynomials: 15 (feedback) and 13 (redundancy) in octal, and one *S*-interleaver. The *S*-interleaver is a random type interleaver. Therefore, unlike the pure random interleaver, a minimum interleaving distance equal with *S* is forced by construction. In this case *S* has the value 27.

Modulation: It refers to the baseband modulation, that consists on the mapping of the input bits to complex symbols, according to the considered constellation. Via an input parameter, all the digital modulations proposed by the standard (QPSK, 16QAM, 64 QAM) may be simulated. The output of this block consists of complex valued modulation symbols.

OFDMA Mapping: This is a complex function, depending on a large number of input parameters. The block implements the permutation strategy and covers the distributed permutation types (DL and UL PUSC and DL FUSC). Among its input parameters, we mention: the total number of carriers in the system, permutation type or permutation base (a critical input parameter for the permutation process, that decides how the physical subcarriers are mapped to subchannels). Another input parameter is the total granted resource, that is the number of subcarriers that will be modulated by data, for the current OFDM symbol. In practice, this resource varies on a frame by frame basis, according to the traffic needs in the cell for a certain moment of time. The output of this block is a sequence of logical indexes that gives a complete map of the subcarriers: subcarriers that will be modulated by data, pilot subcarriers, guard subcarriers and the DC subcarrier. This is a valuable information for the subsequent block, that implements the OFDM modulation.

IFFT: This block implements the OFDM modulation. Its output will be a discrete version of the OFDM symbol (2):

$$s[n] = \frac{1}{N}\sum_{k=0}^{N-1} X[k]\cdot e^{jk\frac{2\pi}{N}n}, \quad n = 0,\ldots,N-1 \qquad (2)$$

Under certain conditions, this equation matches relation (1), which allows a simple implementation of the multi-carrier modulator. Only those positions *k* corresponding to the data subcarriers (as given by OFDMA mapping) will be modulated by the data.

Theoretically, this block is preceded by a serial to parallel converter, and, at its output, another block converts the data back to its serial format. The two converters are practically incorporated by the IFFT transform, as it is implemented in Matlab. Hence, there is no need for explicit implementation of these blocks in our simulator.

Adding CP: The cyclic prefix (CP) consists in a copy of the last samples composing the OFDM symbol in front of it. This function is built according to IEEE 802.16e specifications, which define 4 possible values for the ratio between the duration of the cyclic prefix and the duration of the useful OFDM symbol, i.e. $G \in \{1/4, 1/8, 1/16, 1/32\}$.

Channel: The channel adds a white noise of a certain variance to the useful signal. Flat and frequency selective Rayleigh fading is envisioned for further versions of the simulator.

Receiver: The complementary blocks are implemented in the receiver: the CP is removed, subcarriers are demodulated via the FFT transform, and then subcarrier demapping is performed. Next blocks are somehow incorporated in the decoder, since the decoding scheme which is used takes "soft inputs" (i.e. I and Q components affected by noise) at its input, whereas at its output we will have directly a "hard decision" on the transmitted bits. The decoder uses the Max-Log-MAP version of the decoding algorithm [6]. This suboptimal version is preferred in practice to optimal MAP due to its low computational complexity while keeping near-optimal performance. We have considered, at the decoder, a maximum iteration number equal to 15, with stop criterion iteration, based on A Posteriori Probability, APP [7]. BER and BLER statistics may be computed.

IV. SIMULATION RESULTS

The WiMAX simulator, presented in this paper, allows a better understanding of the processes involved at the PHY layer in WiMAX. Furthermore, quantitative results may be provided by the computation of BER and BLER statistics, in different scenarios.

Thus, by running the simulator, the composition of subchannels and segments can be identified. Furthermore, the data and pilot carriers may be differentiated. Such a result is shown in fig. 4. In this figure, the subcarriers that compose *segment 0* in DL-PUSC 512 are identified in the physical spectrum. In this case, the segment is composed of 120 data subcarriers, partitioned onto 5 subchannels. The pilots

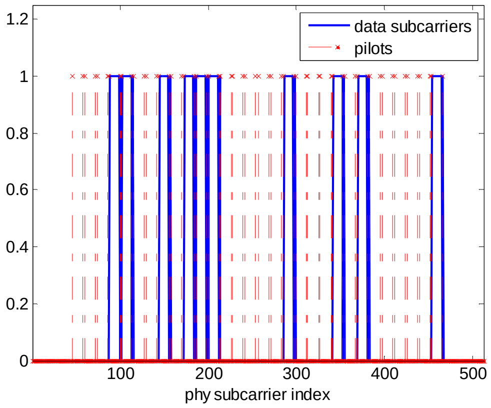

Fig. 4: Segment 0 composition and pilot subcarriers for DL-PUSC 512.

from the whole spectrum (not only those belonging to segment 0) are also shown. We may highlight the concept of frequency diversity: the data subcarriers belonging to segment 0 are spread over the dedicated bandwidth.

Firstly, the simulation chain was validated by transmitting data through an ideal channel (the block AWGN from the simulator was by-passed) and by measuring the BER. As expected, the BER in this case is 0, showing that the chain baseband modulation – encoding – mapping - OFDM modulation works correctly. Next, simulations were carried out in noisy channel conditions. Some results are shown in fig. 5 and 6, for two different permutation types.

Given the simple channel model (only the white noise perturbing the signal), the permutation type does not make any difference with respect to the BER performance of the system. This would only mater in frequency selective and time variant channels.

As expected the BER performance of the QPSK modulation is better than for the 16QAM case in UL-PUSC 512 (fig. 6). The strength of the turbo-codes leads to very good BER results. Consequently, at 2dB, BER is already below 0.0001. For BER=0.001, the gain of QPSK versus 16QAM is approximately 3.5 dB.

Practically, the same conclusions may be drawn from fig. 6. This time, the simulation is made for the DL-PUSC 512 mode.

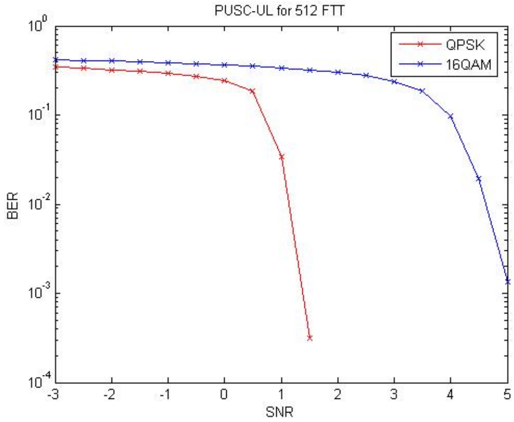

Fig. 5: BER performance for UL-PUSC 512.

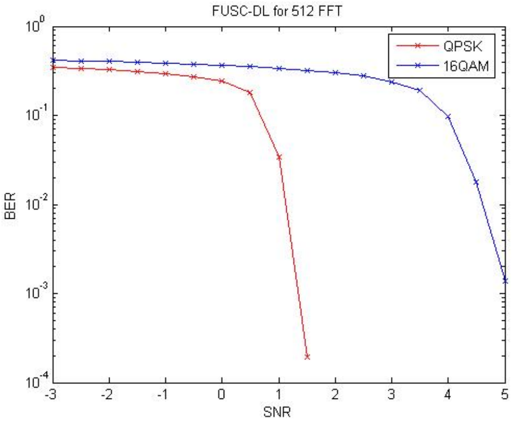

Fig. 6: BER performance for DL-FUSC 512.

V. CONCLUSIONS AND FURTHER WORK

A Matlab based physical layer simulator for WiMAX is presented in this paper. The simulator allows a better understanding of the signal processing steps taking place at the PHY layer corresponding to the IEEE 802.16e specifications. Furthermore, it allows performance evaluation in different scenarios, through BER and BLER computation.

The first improvement that we consider refers to the channel's model. We only considered the simplest case, of a purely AWGN channel. However, a realistic model for the radio channel must take into account its variability in time and its frequency selectivity.

The second improvement will cover some "gaps" in our simulator. Thus, the decoder for 64QAM is not yet implemented. We will extend the implemented permutation types to the adjacent case too, since presently only the distributed permutations are simulated.

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